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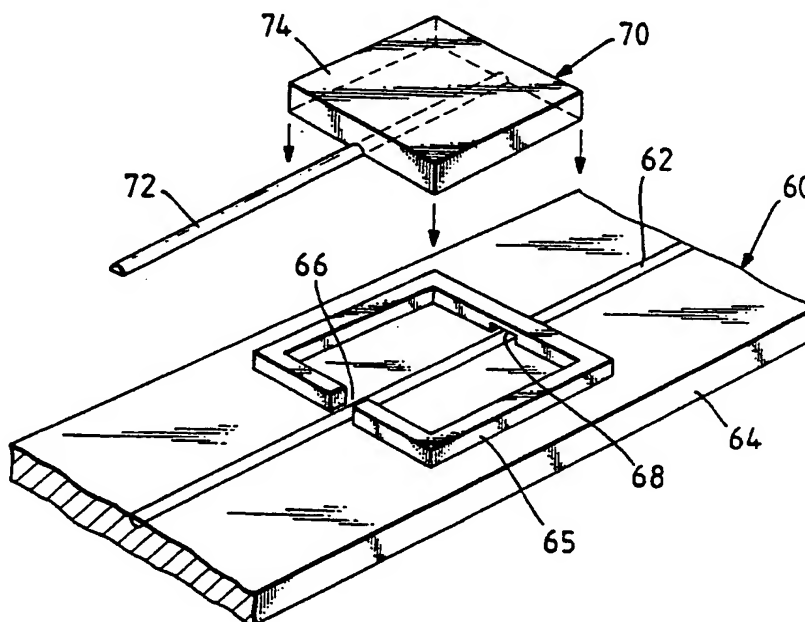
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<p>(21) International Application Number: PCT/GB90/00169 (22) International Filing Date: 5 February 1990 (05.02.90) (30) Priority data: 8902745.2 8 February 1989 (08.02.89) GB (71) Applicant (for all designated States except US): BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY [GB/GB]; 81 Newgate Street, London EC1A 7AJ (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): SMITH, David, William [GB/GB]; Braeside Mill Lane, Campsea Ashe, Woodbridge, Suffolk IP12 0PL (GB). CASSIDY, Stephen, Anthony [GB/GB]; 79 Humber Doucy Lane, Ipswich, Suffolk IP4 3NU (GB). HEALEY, Peter [GB/GB]; 31 Norbury Road, Ipswich, Suffolk IP4 4RQ (GB).</p>		<p>(74) Agent: GREENWOOD, John, David; British Telecommunications public limited company, Intellectual Property Unit, 151 Gower Street, London WC1E 6BA (GB). (81) Designated States: AU, CA, JP, US. Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>

(54) Title: OPTICAL INTERCONNECTION NETWORK



(57) Abstract

An optical interconnection network comprises an optical bus (60) formed by a D-fibre (62) embedded in a thermoplastic substrate (64) with the flat of the D-fibre (62) flush with the top surface of the substrate. A module (70) similarly constructed is dimensioned to be a push fit in a wall structure (65) formed on the substrate (64) with the fibres (72) and (62) in a position to evanescently couple optical signals from one fibre to the other.

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OPTICAL INTERCONNECTION NETWORK

This invention relates to optical interconnection networks (for optically interconnecting one or more transmitter stations with one or more receiver stations).

5 Photonics technology could play a significant role in future telecommunications and computer switching systems within which areas there will then be a requirement for large non-blocking interconnect systems, for example, which each of say 10,000 transmitters will need to be independantly
10 connectable to any one of 10,000 receivers. Such large systems are not presently commercially achievable by known optical switching systems. Further, small systems which can be achieved at the present time are not in general susceptible to ready expansion should new transmitters or receivers need to be
15 added to the network.

It is an object of the present invention to provide an optical interconnection network which largely overcomes these disadvantages. According to a first aspect of the present invention an optical interconnection network comprises an
20 optical bus having at least signal optical waveguide; at least one module having at least one module optical waveguide; the optical bus and module being provided with co-operable coupling means for releasably coupling each module to the optical bus such that there is evanescent coupling between module optical
25 waveguide and the bus optical waveguide.

5 The modules provide optical coupling to or from the optical bus waveguide as required. An optical interconnection network according to the present invention can be readily extended by locating additional modules such that they are coupled to the optical bus.

10 According to a second aspect of the invention, a method of using an interconnection network according to the present invention comprises transmitting from at least one optical module signals which form a hierarchy of at least two independent multiplexing methods. For example, the transmitters can combine wavelength and time division multiplexing each being transmitter channel being identified by a unique combination of channels from the sets of available wavelength and time division channels. A receiver module can
15 select the required transmitter signal by demultiplexing the hierarchy of multiplexes accordingly. Other combinations of multiplexing methods, and hierarchies greater than two may be employed.

20 Spatial multiplexing is readily included by providing the signal optical bus with additional waveguides, the receiver modules being provided with means for selecting a multiplex from the appropriate waveguide.

25 The allocation of the channels of the various multiplexes used in the hierarchy may be dedicated, i.e. fixed, for each modules, or assignable on a demand basis.

30 Preferably, the interconnection network will employ wavelength multiplexing as one of the hierarchy of multiplexes. This can be achieved by providing each transmitter module with a fixed or tunable source of optical radiation, for example a laser, or by providing a reference optical bus of at least two reference optical waveguides each couplable to an optical source of a distinct wavelength, each transmitter module being evanescently couplable to at least one of waveguides of the reference optical bus. The invention
35 permits a hierarchy of wavelength, spatial and other multiplexing systems to be employed allowing a larger

interconnect network to be formed than presently possible using any one of such multiplexing systems individually and the use of modules optically interfacing to the busses provides, in conjunction with the hierarchical multiplexing; a readily extendable network.

Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a first embodiment of the present invention;

Figure 2 is a schematic diagram of a second embodiment of the present invention in which the receiver modules employ coherent homodyne optical demodulator;

Figure 3 is a schematic diagram of a third embodiment of the present invention in which the receiver modules employ coherent heterodyne optical demodulators; and

Figure 4 is a perspective schematic view of an optical bus and a module according to the present invention.

Referring to Figure 1 an interconnect network 2 has a reference bus 4 of m optical waveguides R_1 to R_m each coupled to a respective optical source of distinct wavelength λ_1 to λ_m shown collectively as a reference generator 8, and a signal bus 10 of N optical waveguides S_1 to S_N . For clarity there is shown only one transmitter module T_i of upto $N \times M$ possible transmitter modules and one receiver module 14 of up to $N \times M$ possible receiver modules connectable to the network of this particular embodiment.

The transmitter module 12 in this example when fixed in position relative to the busses 4 and 10 has a first and second group of waveguides 16 and 18 evanescently coupled to the waveguides of the busses 4 and 10 respectively. Each waveguide of the group of waveguides 16 is coupled to one of the waveguides R_i and in turn is optically coupled to a reference

selector switch 20 which is arranged to couple one of the waveguides R_i to an optical modulator 22. The modulator 22 modulates the carrier signal λ_i coupled from waveguide S_i with the information signal to be transmitted. The output of the modulator 22 is couplable via a connector switch 24 to a selected one waveguide of the group of waveguides 18 and hence to a selected one of the waveguides S_i .

The receiver module 14 includes a group of waveguides 26 and an N to 1 selector switch 28 which in the same manner as the selector switch 16 and waveguides 16 of the transmitter module 12 can selectively couple one of the signal waveguides S_i to a demodulator 29 via a frequency selective optical filter 30.

An example of a means for coupling the waveguides of the busses 4 and 10 the module waveguides of groups 16, 18 and 26 will be described in detail below.

The principle behind the bus architecture of this embodiment present invention is that the signal bus forms a message bearer bus carrying optical signals from the transmitter modules in a manner that is accessible to the receiver modules and that the reference bus provides a range of optical frequencies of carrier signal which can be selected by a given transmitter module 12. An interconnection path is established by selecting one wavelength of carrier signal by means of the selector switch 20 modulating the carrier so obtained by the message information and then connecting the modulated carrier via the connector switch 24 to the selected signal waveguide S_i .

Each waveguide S_i can therefore carry a wavelength multiplex of M wavelengths, each transmitter being associated with a unique combination of wavelength λ_i and waveguide S_j .

A receiver can select the information signal to be received by connecting the appropriate waveguide S_j via the signal selector switch 28 and passing only the required wavelength

λ_i to the optical demodulator by means of the frequency selective filter 30.

5 The principle of using a hierarchy of multiplexing techniques can be extended by, for example, using time coding of transmission, coding of transmissions and so. Thus, for example a three layer hierarchy of space, frequency (as exemplified by the Figure 1 arrangement) together with time domain multiplexing of the information signals to the modulators 22, each with a dimension of 100 channels would
10 provide an interconnect power of 10^6 . This multiplication of the multiplexing power of each multiplexing technique therefore allows a much greater interconnect power than available from any one technique alone.

15 The ability to removably couple transmitter and receiver modules onto the busses 4 and 10 permits ready growth of the network by the additional of modules until all the multiplex combinations are used when whereupon one additional multiplex may be added to the hierarchy to further increase the interconnect power of the network and for transmitter and
20 receiver modules to be unplugged and moved to different locations on the optical bus as necessary. Thus, for example, once NxM transmitters and receivers had been connected to the network, the introduction of P time slot channels would allow expansion of the network to NxMxP transmitters and receivers.

25 The transmitter modules 12 and 14 can independantly, be installed with dedicated channels, ie. the selection and connector means coupling the modulator/demodulators to a single predetermined waveguide of each bus, in which case the groups of waveguides 16, 18 and 26 need comprise only one waveguide
30 without a requirement for selector or connector switches, or they may be as shown in Figure 1 which allows the transmitters and receivers to select the wavelength and space channel combination for transmission and reception.

Alternatively, the transmitter modules may be provided with fixed or tunable optical sources, for example lasers, which eliminates the need for the reference bus 4. If two or more non-spatial hierarchies are employed then the signal bus need have only one waveguide, each transmitter and receiver module being evanescently coupled to it exclusively. In the case of spatial multiplexing, i.e. two or more waveguides in the signal optical bus, the modules can, analogously to the wavelength multiplexing example above, be dedicated or assignable. If the modules are dedicated then the signal connector or signal selector switch may be eliminated, the optical waveguide of the modules being located so that it couples to the required waveguide of the signal optical bus when co-located with the bus.

Referring now to Figure 2, an interconnection network 32 is shown which is as the network 2 except that the wavelength selection in the receiver module 14 is not by way of a tunable filter 30 but by means of coherent, homodyne detection. This is achieved by means of an additional selector switch 34 which selectively couples one of the reference waveguides R_1 to the coherent demodulator 36 corresponding to the wavelength channel to be demultiplexed.

Heterodyne detection can be achieved in a similar manner as by the incorporation of frequency shifters 38 between the reference generator and the receiver modules 14 of the network of Figure 2 as shown in Figure 3.

A possible structure of the busses 4, 10, of the groups of waveguides 16, 18, 26 and a the method of inter-coupling them will now be described with reference to Figures 4 and 5. The busses were fabricated using optical fibres having a D-shaped cross-section, "D-fibres". This fibre is formed by cutting away one side of a preform of a normal optical fibre so that one side is close to the core. When drawn this produces a long, continuous length of fibre with a lateral flat surface

close to the core 44 (as shown on Figure 4 with respect to only one of the figures 44). In this particular embodiment the core was about $0.5\mu\text{m}$ from the flat surface.

5 The three D-fibres 40, 42 and 44 when placed with their centres $250\mu\text{m}$ apart and press-moulded into a polymer substrate 50 30mm . The moulding was performed against a heated optical flat which ensure that the flat surfaces of the D-fibres align accurately in a common plane. The fibres 40, 42 and 44 where then cleaved and fusion spliced to standard single mode optical
10 fibre in turn splices to the tails of semiconductor lasers of wavelength $1.3\mu\text{m}$ (not shown). A second substrate was fabricated (not shown), the D-fibres being spliced at one end of single mode tails to couple them to optical power meters.

15 The two of the waveguide substrate 50 coupled to the lasers (not shown) performed the function of the optical bus 4 carrying the power. The third acts as a single signal bus waveguide but was coupled to a laser also to measure the coupling performance. The second substrate, acting as one of the module couplers, was positioned so it overlapped the first
20 by 0.5mm . The close proximity of the cores provided evanescent coupling between them allowing a small fraction of the optical power to be tapped out of the fibre bus into the corresponding waveguide of the second substrate.

25 A photomicrograph of the substrate 50 showed that the D-fibres appear as ridges $0.5\mu\text{m}$ high and $85\mu\text{m}$ wide, the remainder of the fibre diameter being concealed by polymer 'ears' which grip the fibres and slope away to the general substrate level. The top points of the flat surfaces of the fibre occupy a plane to well within an accuracy of 100nm with a
30 spacing of $250\mu\text{m} \pm 20\mu\text{m}$.

The power splitting ratios between fibres are displayed in the table below, where the primed numerals indicate the equivalent fibres on the second substrate.

- 8 -

	fibre	40	42	44
5	40'	-37dB	<-78dB	<-78dB
	42'	<-78dB	-39dB	<-78dB
10	44'	<-78dB	<-78dB	-35dB

The cross talk between unwanted pairs of fibres was below the measurement limit of -78dB. The ratio of wanted to unwanted signal was therefore at least 43dB at each tapping point.

A detailed treatment of the tolerancing of the bus and connector substrates shows that with the present design, a lateral and angular misalignment 250 μ m, and 1 $^{\circ}$ respectively, a fibre height variation of 0.75 μ m, or a wavelength change from 1.3 to 1.5 μ m, each give smaller variation in output power than 3dB. All these parameters are well within achievable engineering limits and have been achieved here. A more critical parameter is the "rocking" of the connector in the two available dimensions. However, by taking advantage of the close tolerance of the planes formed by the D-fibre flats (<100nm), the natural contact of these planes as the connector contacts the bus is well within the tolerance needed. It is obvious that the position of contact along the bus will be immaterial. Many connectors could therefore be connected to the bus along its length.

Each connector substrate in principle only takes up a few mm of space on the D-fibre bus. The optical loss of D-fibre is below 1dB/m. It can therefore be envisaged that by expanding

the present geometries and maintaining the physical tolerances already achieved an optical distribution bus capable of interconnecting large numbers of communicating terminals could be built using present optical technologies.

5 Referring now to Figure 5 an optical interconnection network shows a portion an optical fibre bus 60 having one signal optical D-fibre 62 embedded in a thermoplastic substrate 64. A portion of the fibre 62 lies within a wall structure 65 having a slot 66 and a channel 68 to avoid contact with the
10 flat of the D-fibre 62.

 A module 70 comprising an optical D-fibre 72 embedded in a thermoplastic substrate 74 is dimensioned to be a push fit in the wall structure 68. When pushed into structure 68 the fibres 72 and 62 are held in position to permit evanescent
15 coupling. The fibre 72 extends through the slot 66 to a receiver or transmitter as required.

 The module 70 may be provided with a handle to ease removal of the module 70 from the wall structure 64.

20

CLAIMS

1. An optical interconnection network comprising an optical bus having at least signal optical waveguide; at least one module having at least one module optical waveguide; the optical bus and module being provided with co-operable coupling means for releasably coupling each module to the optical bus such that there is evanescent coupling between module optical waveguide and the bus optical waveguide.
2. A network as claimed in claim 1 in which there is a plurality of signal optical waveguides.
3. A network as claimed in claim 2 in which the module has a module waveguide positioned to couple to a predetermined one of the signal optical waveguides.
4. A network as claimed in claim 2 in which a module has a plurality of module waveguides one positioned to couple to each of the signal optical waveguides, an optical signal transmitting means, and first transmitter selection means whereby the transmitting means is couplable to a selected one of the signal waveguides.
5. A transmitter as claimed in claim 4 in which the optical signal transmitting means comprises a tunable laser.
6. A network as claimed in any one of claims 1 to 5 in which a module has a plurality of module waveguides one positioned to couple to each of the signal optical waveguides, a receiving means, and is provided with first receiver selection means whereby the receiving means is couplable to a selected one of the signal waveguides.
7. A network as claimed in claim 6 in which the receiving means comprises a tunable optical filter.
8. A network as claimed on any preceding claim in which the optical bus includes two or more reference optical waveguides each coupled to an optical source of a distinct wavelength.
9. A network as claimed in claim 8 as dependant on claim 4 in which the transmitter module has a module waveguide positioned

to couple to a predetermined one of the reference waveguides and means for modulating an optical signal coupled from said reference waveguides.

10. A network as claimed in claim 8 in which the transmitter module has a plurality of module waveguides positioned to couple to each of the reference waveguides and second transmitter selection means whereby the transmitting means is couplable to a selected one of the reference waveguides.

11. A network as claimed in any of claims 8 to 10 in which the receiving means comprises a coherent demodulator, and the receiver module has a module waveguide positioned to couple to a predetermined one of the reference waveguides whereby the coherent demodulator is couplable to one of the optical sources.

12. A network as claimed in any one of claims 8 to 10 in which the receiving means comprises a coherent demodulator, the receiver module has a plurality of module waveguides positioned to couple to each of the reference waveguides and a second receiver selection means whereby the receiving means is couplable to a selected one of the reference waveguides.

13. A network as claimed in any preceding claim in which the optical bus comprises D-fibres the flat surfaces of which lie on a common plane.

14. A transmitter module for use in a network as claimed in any preceding claim.

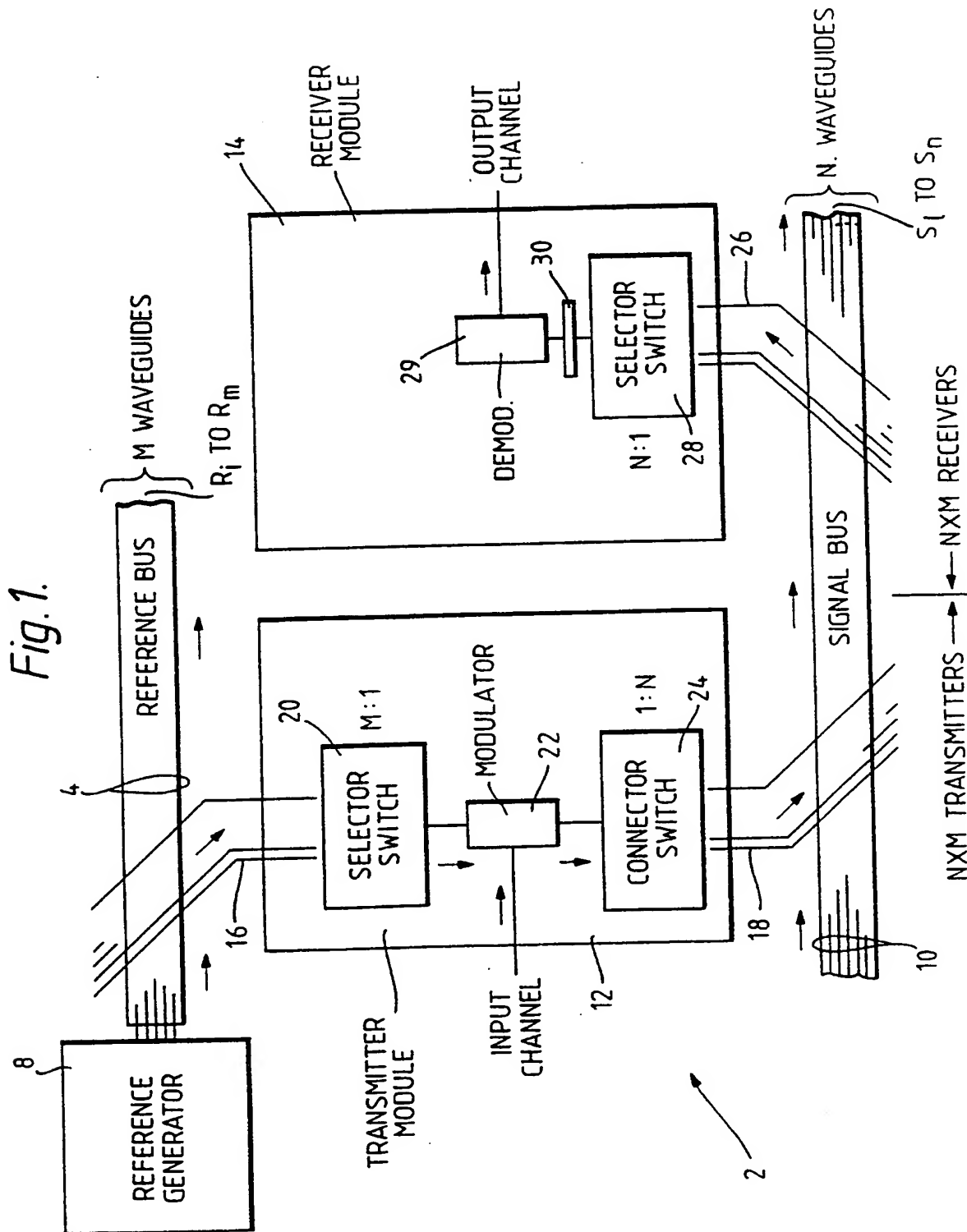
15. A module for use in a network as claimed in any one of claims 1 to 14.

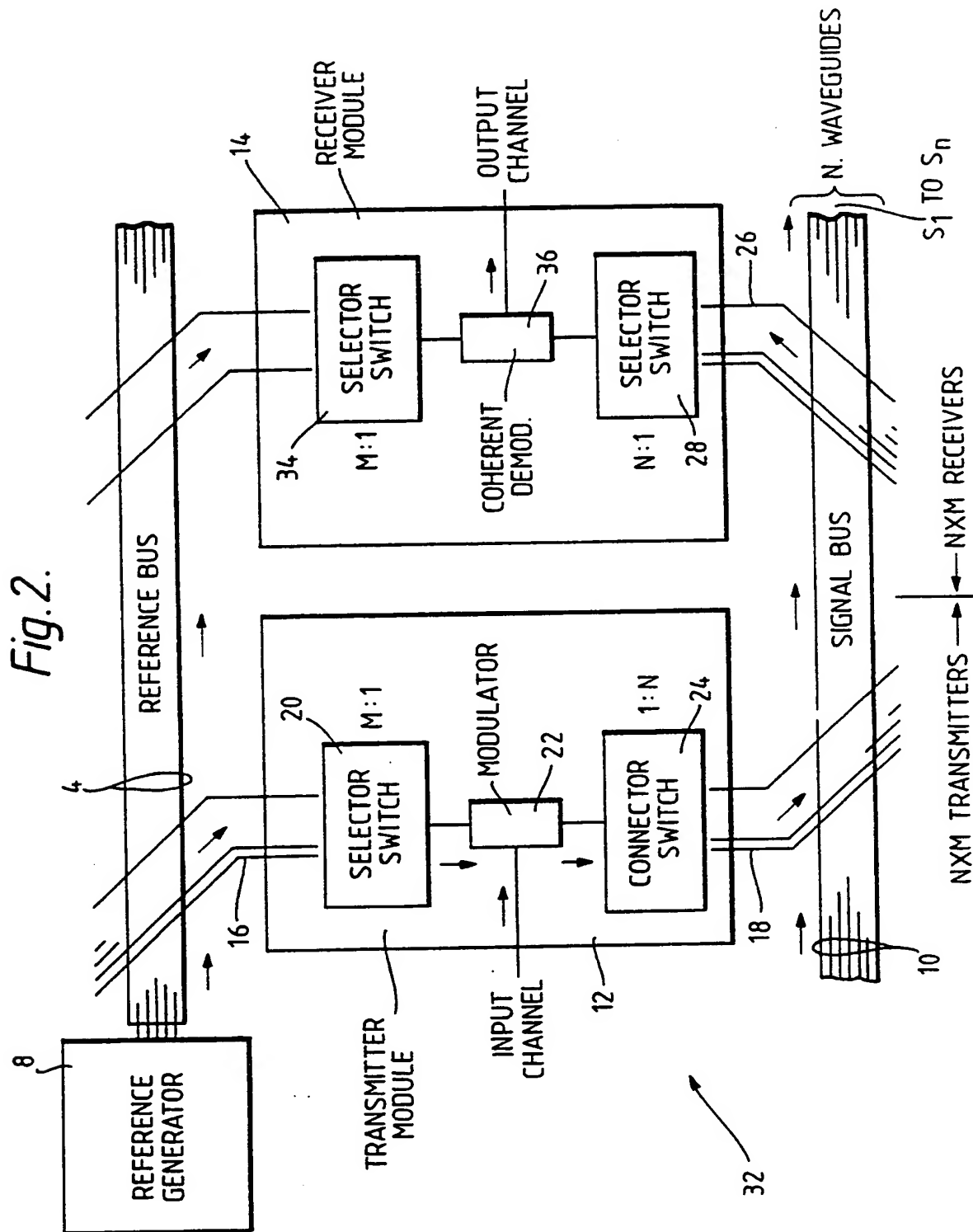
16. A module as claimed in claim 15 in which the module waveguides comprises D-fibres the flat surfaces of which lie on a common plane.

17. A method of using a network as claimed in any one of claims 1 to 13 comprising transmitting from at least one module optical signals which form a hierarchy of at least two independant multiplexing methods.

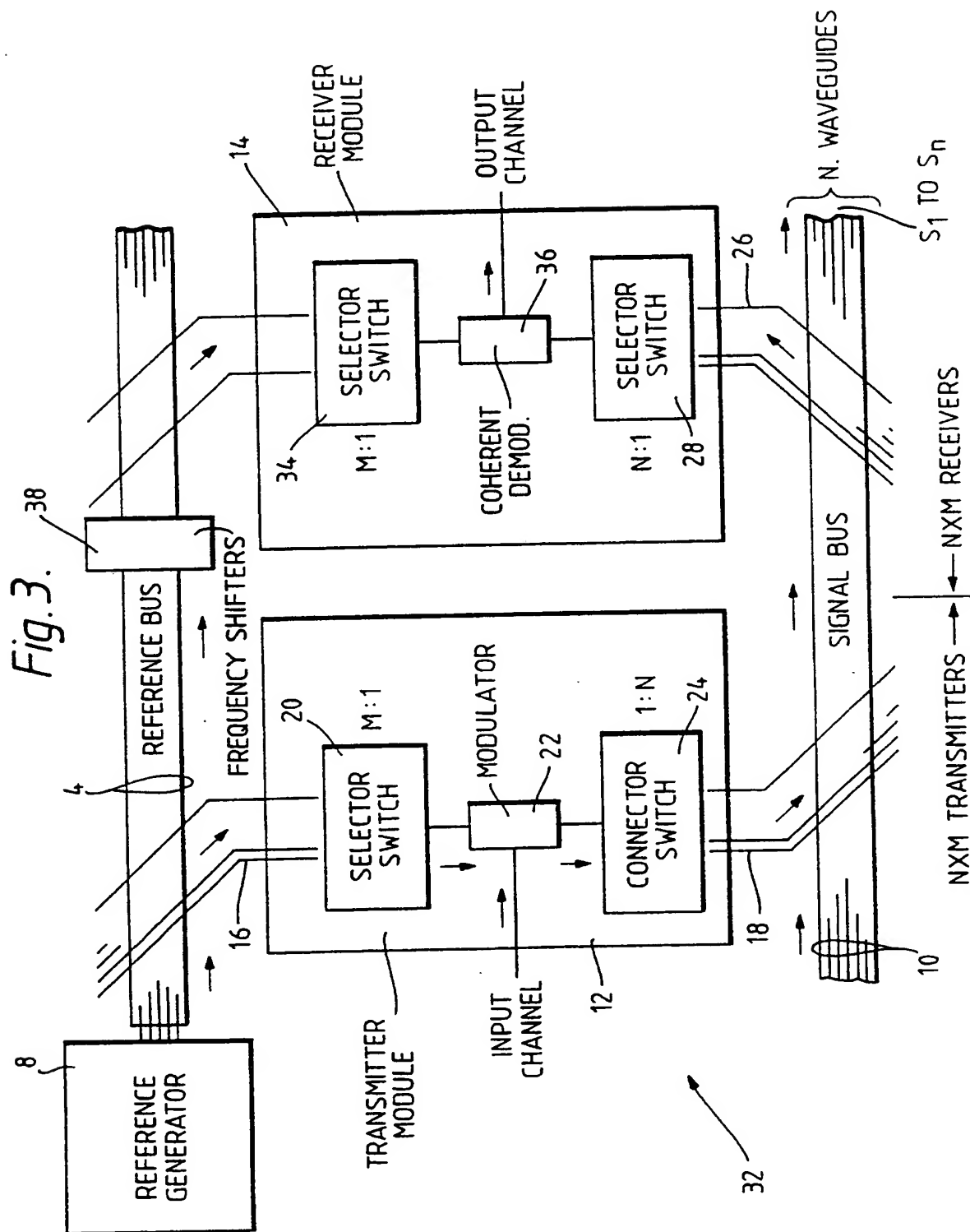
18. A method as claimed in clam 17 in which one of the multiplexing methods comprises wavelength multiplexing.

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SUBSTITUTE SHEET

4/4

Fig. 4.

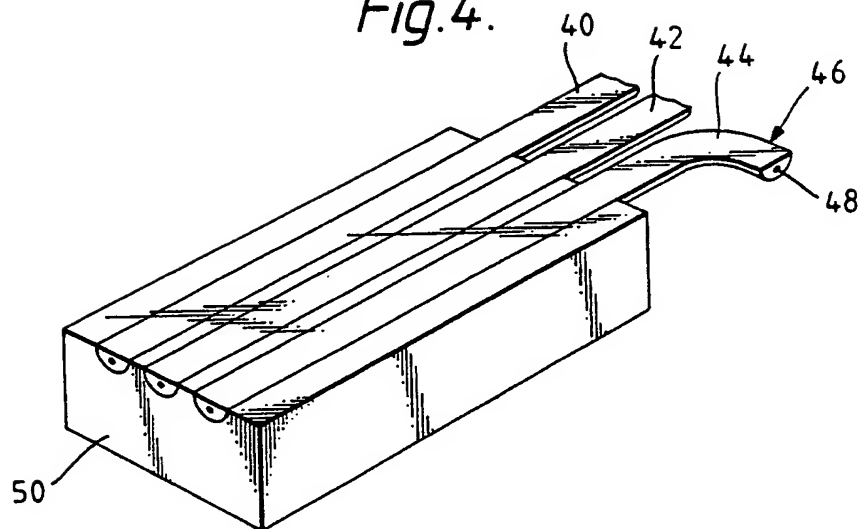
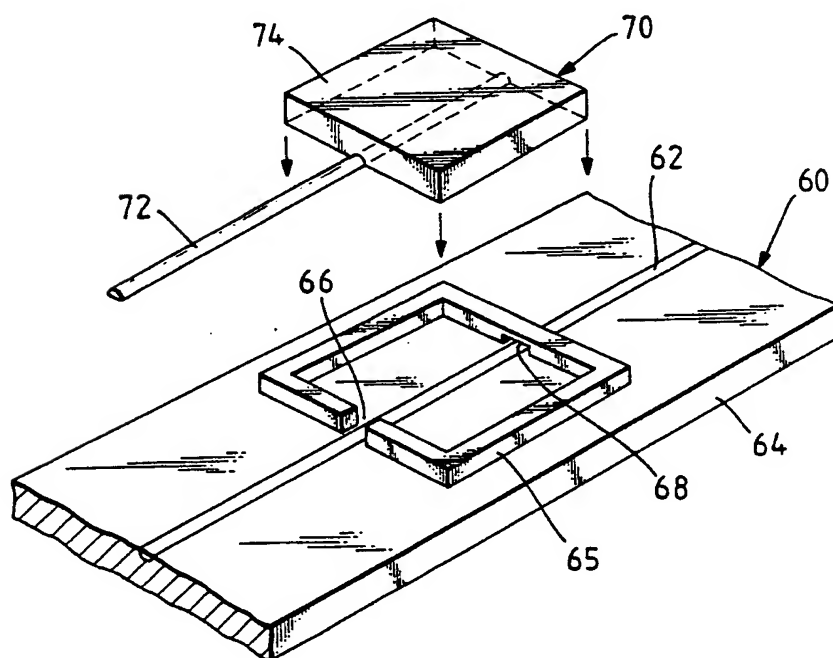


Fig. 5.



SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/GB 90/00169

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply indicate all) [*] According to International Patent Classification (IPC) or to both National Classification and IPC IPC ⁵ : H 04 B 10/20, H 04 J 14/00																													
II. FIELDS SEARCHED <div style="display: flex; justify-content: space-between; margin-top: 10px;"> Classification System Minimum Documentation Searched⁷ </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> IPC⁵ Classification Symbols </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> H 04 B, H 04 J </div> <div style="text-align: center; margin-top: 10px; font-size: small;"> Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched⁸ </div>																													
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹ <table style="width: 100%; border-collapse: collapse; font-size: x-small;"> <thead> <tr> <th style="width: 10%;">Category¹⁰</th> <th style="width: 70%;">Citation of Document,¹¹ with indication, where appropriate, of the relevant passages¹²</th> <th style="width: 20%;">Relevant to Claim No.¹³</th> </tr> </thead> <tbody> <tr> <td style="text-align: center; vertical-align: top;">X</td> <td style="vertical-align: top;">WO, A, 85/00484 (ATT) 31 January 1985 see page 8, lines 7-30</td> <td style="text-align: center; vertical-align: top;">1, 2, 4</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td style="text-align: center; vertical-align: top;">--</td> <td style="text-align: center; vertical-align: top;">13-18</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">X</td> <td style="vertical-align: top;">US, A, 4592043 (WILLIAMS) 27 May 1986 see column 4, lines 6-50; figure 12; column 21, line 52; column 22, lines 51-55</td> <td style="text-align: center; vertical-align: top;">1, 2, 4</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">Y</td> <td></td> <td style="text-align: center; vertical-align: top;">5</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td style="text-align: center; vertical-align: top;">--</td> <td style="text-align: center; vertical-align: top;">3, 6, 8-18</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">Y</td> <td style="vertical-align: top;">EP, A, 0228888 (POLAROID) 15 July 1987 see abstract; claims 1-2; page 2, lines 22-37</td> <td style="text-align: center; vertical-align: top;">5</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td style="text-align: center; vertical-align: top;">--</td> <td style="text-align: center; vertical-align: top;">6, 8-12, 14, 15, 18</td> </tr> <tr> <td></td> <td style="text-align: center; vertical-align: bottom;">./.</td> <td></td> </tr> </tbody> </table>			Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³	X	WO, A, 85/00484 (ATT) 31 January 1985 see page 8, lines 7-30	1, 2, 4	A	--	13-18	X	US, A, 4592043 (WILLIAMS) 27 May 1986 see column 4, lines 6-50; figure 12; column 21, line 52; column 22, lines 51-55	1, 2, 4	Y		5	A	--	3, 6, 8-18	Y	EP, A, 0228888 (POLAROID) 15 July 1987 see abstract; claims 1-2; page 2, lines 22-37	5	A	--	6, 8-12, 14, 15, 18		./.	
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<div style="display: flex; justify-content: space-between; font-size: x-small;"> <div style="width: 45%;"> <p>[*] Special categories of cited documents: ¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"D" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p> </div> </div>																													
IV. CERTIFICATION <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; border-bottom: 1px solid black; padding: 5px;"> Date of the Actual Completion of the International Search <div style="text-align: center;">10th May 1990</div> </td> <td style="width: 50%; border-bottom: 1px solid black; padding: 5px;"> Date of Mailing of this International Search Report <div style="text-align: center;">13.05.90</div> </td> </tr> <tr> <td style="border-bottom: 1px solid black; padding: 5px;"> International Searching Authority <div style="text-align: center;">EUROPEAN PATENT OFFICE</div> </td> <td style="border-bottom: 1px solid black; padding: 5px;"> Signature of Authorized Officer <div style="text-align: center;">F.W. HECK </div> </td> </tr> </table>			Date of the Actual Completion of the International Search <div style="text-align: center;">10th May 1990</div>	Date of Mailing of this International Search Report <div style="text-align: center;">13.05.90</div>	International Searching Authority <div style="text-align: center;">EUROPEAN PATENT OFFICE</div>	Signature of Authorized Officer <div style="text-align: center;">F.W. HECK </div>																							
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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	DE, A, 3218022 (TE KA DE) 25 November 1982 see figure 2	13,16
A	ECOC 87, Technical Digest, volume III, Post Deadline Papers; 13-17 September 1987, Helsinki, Finland, CPEF, (Helsinki, FI), I.P. Kaminow et al.: "FDM.FSK star network with a tunable optical filter demultiplexer", pages 17-20 see page 17, first three paragraphs	7
A	EP, A, 0221695 (STC) 13 May 1987 see figure 2; column 4, lines 34-55	13,16

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.**

GB 9000169

SA 34330

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 06/06/90. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		CA-A- 1247704	27-12-88
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